

N66 29389

FACILITY FORM 802

(ACCESSION NUMBER)	(THRU)
15	1
(PAGES)	(CODE)
TMX-56806	01
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

A SIMULATOR STUDY OF T-TAIL AIRCRAFT IN DEEP STALL CONDITIONS

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Presented at The AIAA/RAeS/JSASS Aircraft Design and Technology Meeting

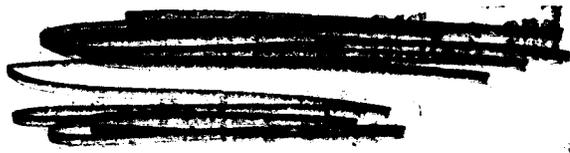
GPO PRICE \$ _____

CFSTI PRICE(S) \$ _____

Hard copy (HC) \$ 1100

Microfiche (MF) 150

653 July 65



Los Angeles, California
November 15-18, 1965

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INTRODUCTION

For a number of years, jet fighter airplanes with high horizontal tails have been in use by the armed forces of this and other countries. Several of these airplanes have displayed undesirable pitch-up tendencies that have been studied in some detail, as for example in reference 1. More recently, several "T-Tail" transport designs with engines mounted on the aft end of the fuselage have been put in service. Some prototype versions of these designs have displayed a tendency in early test flights to pitch up into what has been called a deep stall. This is a stall continuing to extremely high angles of attack from which recovery is difficult.

The problem is illustrated in figure 1. Immersion of the horizontal tail into the combined wake of the wing, engines and fuselage occurs at an angle of attack greater than the wing stall angle. At the point that the tail has become immersed in the wake, the wing flow has progressed to a well developed separation. The net effect is to produce a nonlinear variation of pitching moment with angle of attack that has two stable trim points, the normal one at a low angle of attack and another at a higher angle of attack as shown in figure 2.

The effects of the flow conditions at extreme angles of attack have been measured recently at the NASA Langley Research Center and are reported in reference 2. In the presentation of wind tunnel results of reference 2 it was shown that certain design modifications can alleviate the problem.

Analog simulations were made at three NASA research centers to study the deep-stall recovery problem of T-Tail airplanes. The results have been outlined briefly in reference 3. This paper will present some results of the fixed base simulation at the Langley Research Center in more detail.

Description of Simulation

The airplane designer must be concerned with all contributions to pitching moment in order to determine if deep-stall recovery is possible. The factors that are important are listed in figure 3. These airplane parameters were all accounted for in the simulation. All but the last two factors are combined into a basic configuration index, ΔC_m , which is shown in figure 2. This index is defined with full recovery elevator and is the amount that the pitching-moment curve is above or below the zero axis where a maximum is reached in the high angle of attack region. The configuration illustrated in figure 2 has a positive value of ΔC_m and is one which is capable of a deep-stall lock-in. The lock-in occurs at the stable trim point at high angles of attack with the stick full forward for recovery. For the simulation, a family of pitching moment curves was programmed in an analog computer so as to cover a range of values of the basic index ΔC_m . Of the last two factors listed in figure 3, only the pitch damping was varied in these flight simulations. The airplane wing loading, weight and inertia, typical of a medium size jet transport, were held constant.

The aerodynamic characteristics used in the simulation are illustrated in figure 4. The lift, drag, elevator effectiveness and pitch damping are plotted as functions of angle of attack. It is apparent that the stall break occurs at an angle of attack near 18 degrees and that there is a marked deterioration in elevator effectiveness at high angles of attack. The first configuration investigated had a constant pitch-damping coefficient ($C_{m\dot{q}} + C_{m\dot{\alpha}}$) of -70. The second configuration had a pitch-damping variation with angle of attack shown as a solid line in figure 4. This pitch-damping function represents a change to negative damping in the deep-stall region. The third configuration had a pitch-damping curve that was obtained in wind tunnel tests of the large-tail model of reference 2. This pitch damping curve is shown as the dotted line in figure 4.

The fixed base cockpit used in the simulation, shown in figure 5, was a realistic jet transport arrangement. The instruments receiving primary attention in this

investigation are the two axis attitude instrument, altimeter, rate of climb meter, airspeed and normal acceleration indicators. The analog computer that developed the motions from the pilots' control inputs was programmed for six degrees of freedom.

The investigation consisted of deliberately executed deep stall entries on the simulator followed by recovery attempts. The stalls were made by three test pilots and their performance in recovery has been combined in the presentation of results. The stalls were started at 15,000 feet with idle thrust. Altitude was maintained by increasing back pressure on the yoke as speed decreased. The stall was indicated by a sudden drop in normal acceleration and an increased rate of descent. In order to reach the deep stall conditions, the pilot ignored the stall warning and held the airplane deliberately in the stall until a rate of descent of 4,000 feet per minute had developed. This is well beyond the point of normal recovery. The recovery attempt was then made with full nose down elevator and maximum thrust. The stabilizer was kept at a constant angle for level-flight trim at a speed about forty percent greater than the stall speed.

Results

Typical stall maneuvers are shown in figure 6 for the pilot's first encounter of deep stall and for a recovery after a period of practice on the simulator. On his first encounter, the pilot used his usual recovery technique for conventional aircraft. The pilot believed that the stall recovery was successful, for the attitude angle came down nearly to the horizontal and airspeed increased, and then tended to stabilize. These indications were similar to the pilot's experience with the usual stall recovery and yet the altimeter continued to indicate descent as is characteristic of the deep stall. After a few orientation runs with an angle of attack meter, the picture became clearer and a more successful recovery technique was learned. This technique requires that full recovery elevator deflection be used until the pitch attitude has decreased to a point well below the horizon and there is a definite

increase in airspeed to a value about 75 percent greater than the stall speed. While the airspeed is still increasing, a moderate rate of pull out is started for recovery. Application of thrust was not particularly needed. Although angle of attack indication was helpful in the learning process, the pilot soon was able to make successful recoveries without the angle of attack meter if recovery was possible in the configuration simulated. It is believed, however, that an angle of attack meter would be desirable in an airplane capable of deep stall and that a pilot's recovery performance would be improved as a result.

Pilot performance of stall recovery is given in figure 7 for the configuration with constant damping. Deep-stall lock-in occurred for most of the configurations possessing a positive value of ΔC_m . With this damping, the pilots could not rock out of the deep stall by pumping the elevator through full travel once the stall lock-in occurred. It is significant that while lock-in did not occur for configurations with small negative values of ΔC_m , large altitude losses were experienced.

The second configuration with the variation in damping shown as a solid line in figure 6 was then simulated and compared with the results for constant damping. The comparison is shown in figure 8. The damping as a function of angle of attack was an estimate for a T-Tail configuration based on the change in slope of the moment curve but does not represent wind tunnel data. For this damping function, deep stall lock-in never occurred. Therefore this shows a real benefit of low or negative pitch damping in the deep stall region.

Late in the simulation investigation, data from wind-tunnel measurements of pitch damping of T-Tail models at the Langley Research Center became available. The damping function measured is shown as the dotted line in figure 4. One of these models was the large-tail model of reference 2. The damping measurements of the large-tail model were incorporated in the analog program and the results of stall simulations were compared with the results obtained at the constant pitch-damping value of -70 . The comparison indicated that the results were very much the same as for the pitch damping of -70 . Thus, although there is a loss in damping at high angles of attack,

the small angle of attack range in which low damping occurs makes the damping change ineffective. Accurate measurements of pitch damping would then be of significance for a configuration that is planned as a T-Tail airplane.

All of the results presented thus far were obtained with good lateral stability characteristics that did not deteriorate in the stall. The pilot could control the lateral modes as a minor diversionary task. At one point in the investigation, poor lateral handling qualities based on a combination of wind tunnel data and estimates of some of the lateral and directional damping derivatives were introduced into the simulation. The results of one trial run are shown in figure 9. The pilot could fly this configuration only for a short time. As soon as some disturbance occurred in the beginning of the stall, the airplane quickly became impossible to control. Note the divergence to a 90° bank angle in figure 9. At this point the simulation computer overloaded and the run was terminated.

Conclusions

Results of a fixed-base cockpit simulation of deep-stall in T-Tail aircraft has revealed the following in relation to pilot performance of recovery.

1. A configuration index, ΔC_m has been evaluated. The tests show that lock-in of deep stall occurred when ΔC_m exceeded a small positive value for large pitch damping.
2. For configurations with small negative values of ΔC_m , recovery performance was poor in that large losses in altitude were experienced.
3. Damping in pitch is an important factor in the determination of deep-stall recovery capability. Low pitch damping and negative pitch damping in the deep-stall region are favorable to recovery.
4. Lateral characteristics must not be ignored in stall recovery performance estimates, because it appears that for some configurations control of lateral instability may be an overriding task.

References

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2. Taylor, Robert T. and Ray, Edward J.: Deep Stall Aerodynamic Characteristics of T-Tail Aircraft. NASA Conference on Aircraft Operating Problems. SP-83, May 1965.
3. White, Maurice D. and Cooper, George E.: Simulator Studies of the Deep Stall. NASA Conference on Aircraft Operating Problems SP-83, May 1965.

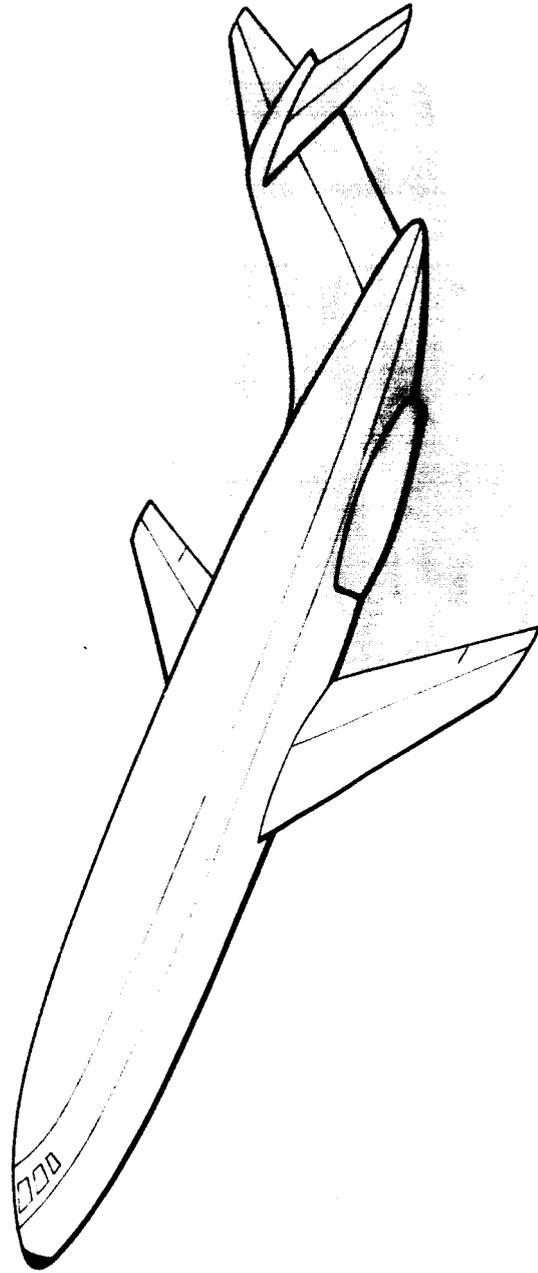


Figure 1.- T-tail aircraft in deep stall.

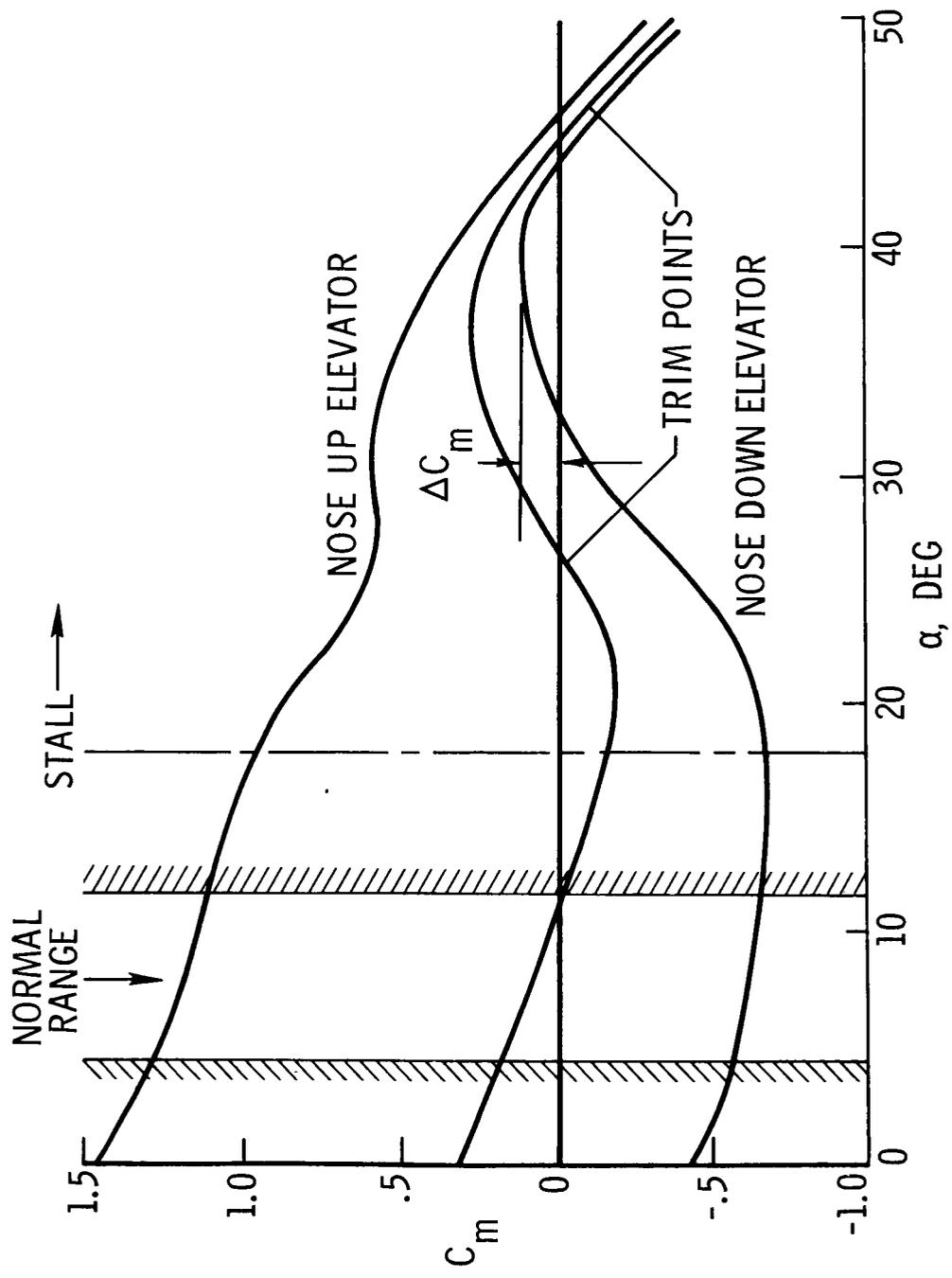


Figure 2.- Pitching-moment data.

PITCHING MOMENT VERSUS ANGLE OF ATTACK

CENTER-OF-GRAVITY LOCATION

ELEVATOR EFFECTIVENESS IN STALL

STABILIZER EFFECTIVENESS IN STALL

THRUST MOMENT

PITCH DAMPING

INERTIA IN PITCH

Figure 3.- Factors in deep-stall recovery.

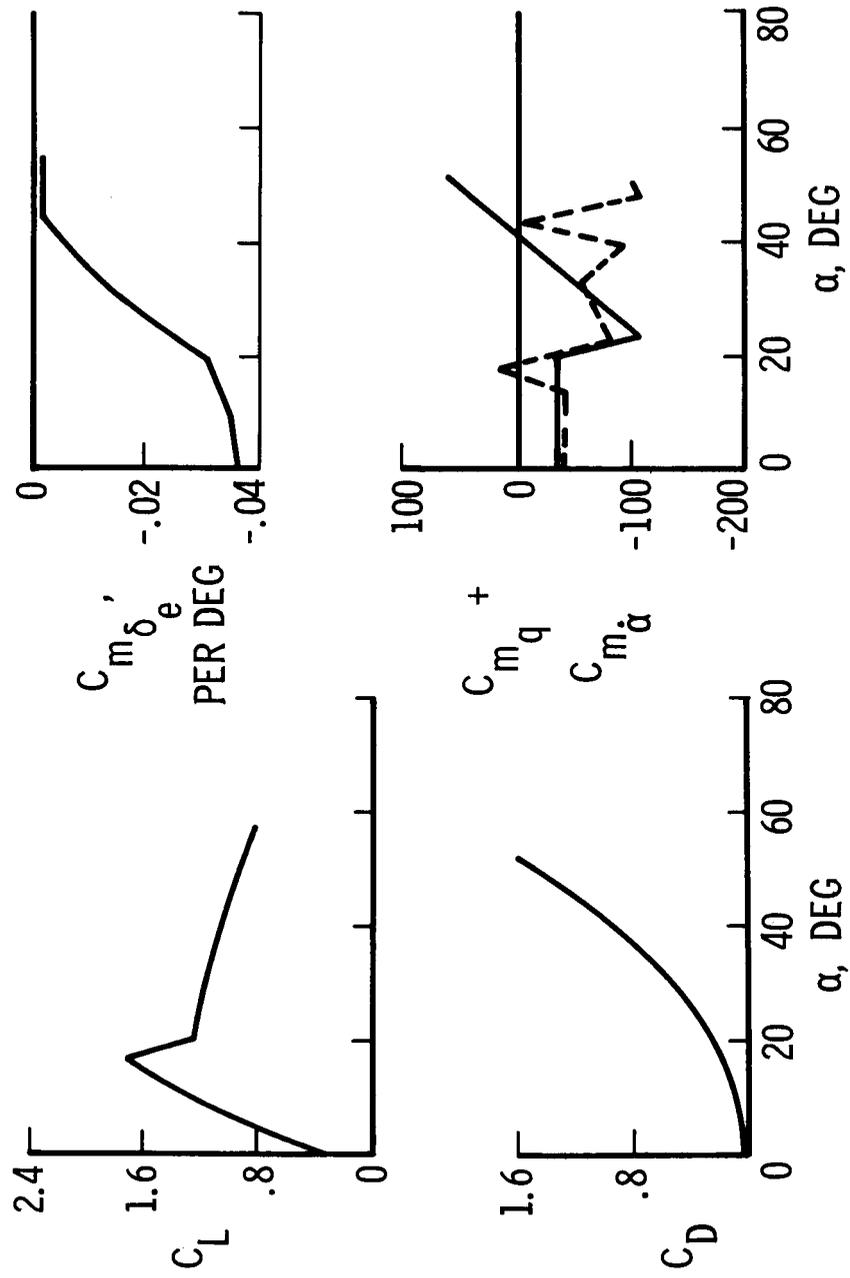


Figure 4.- Aerodynamic characteristics.

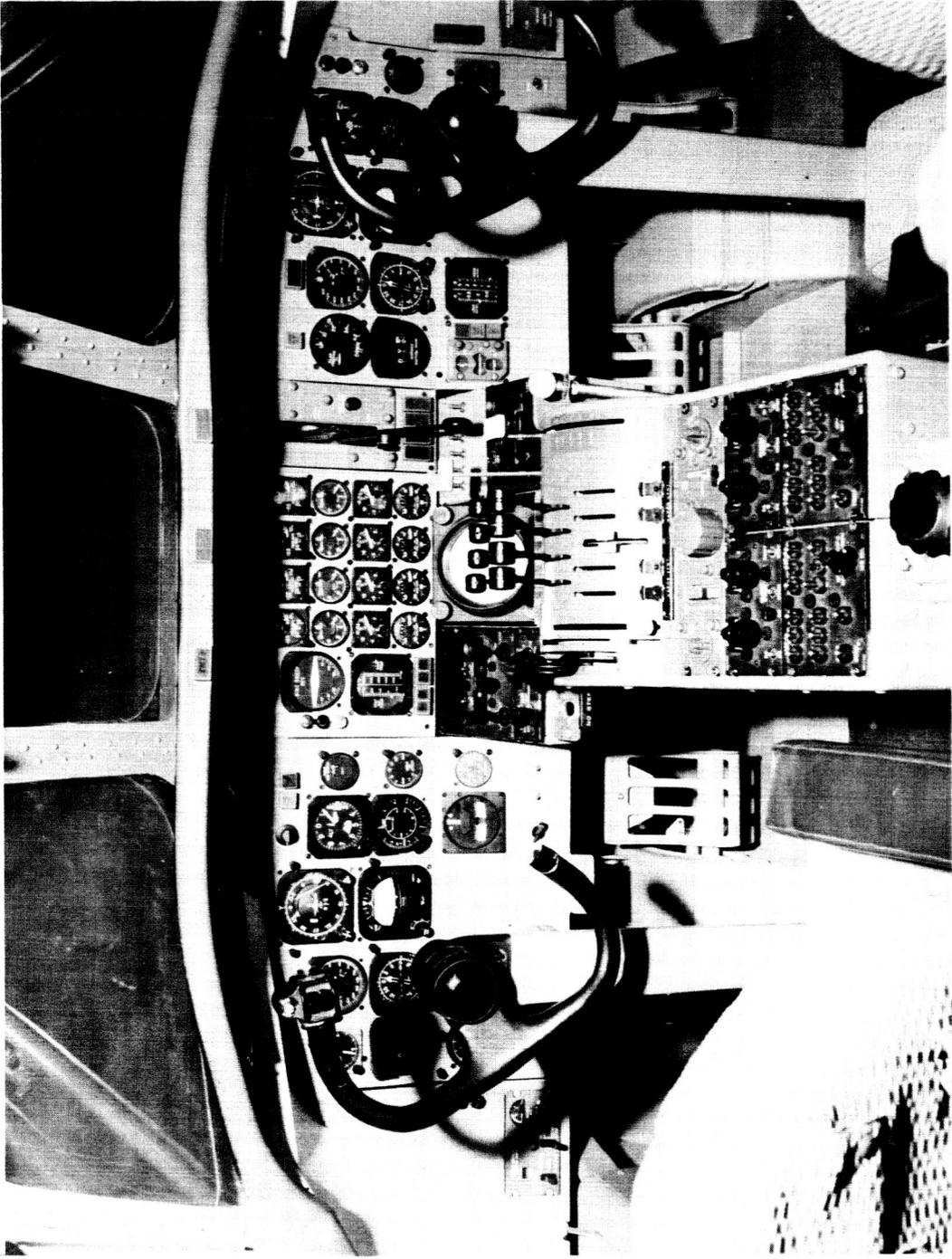


Figure 5.- Simulator cockpit.

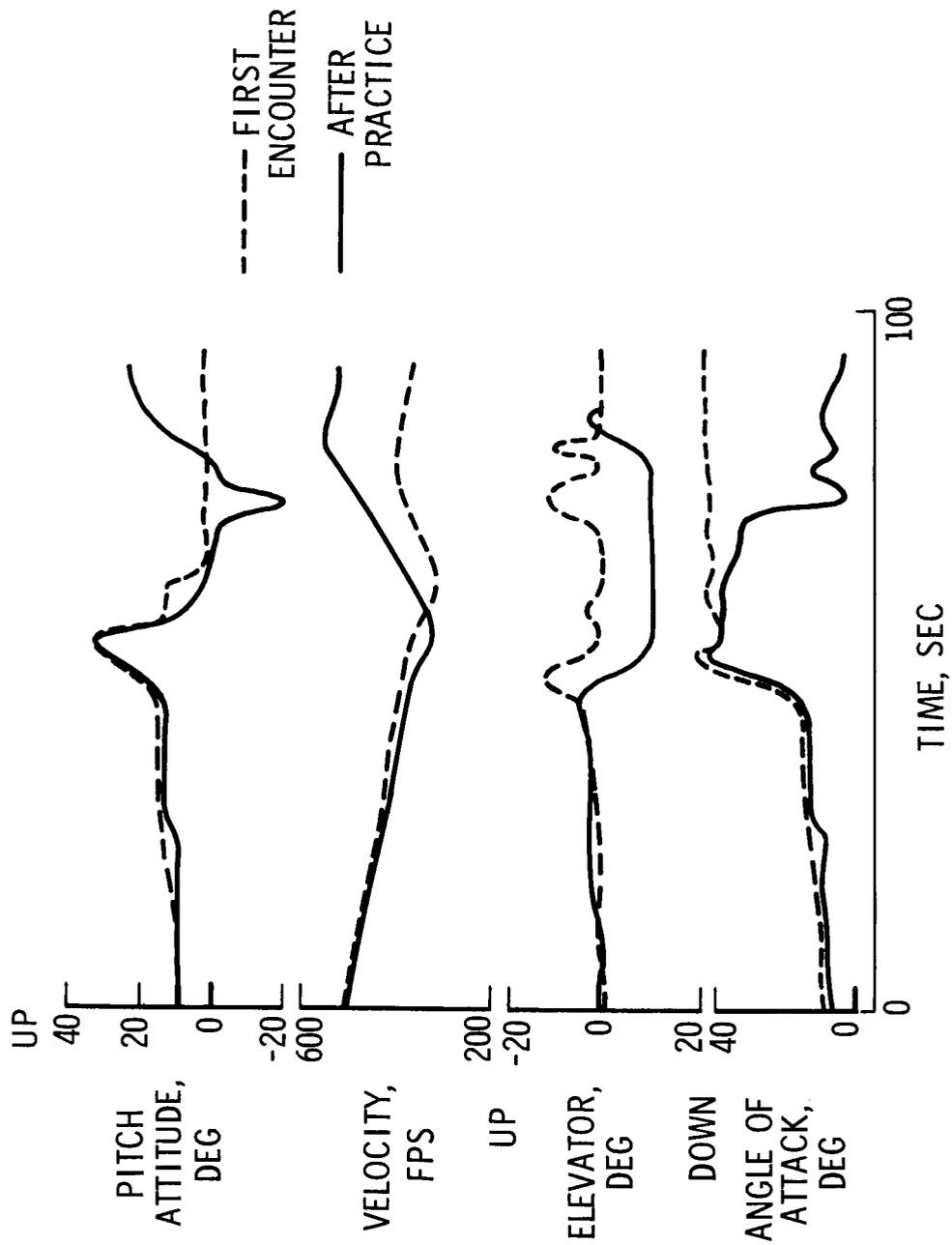


Figure 6.- Stall encounters.

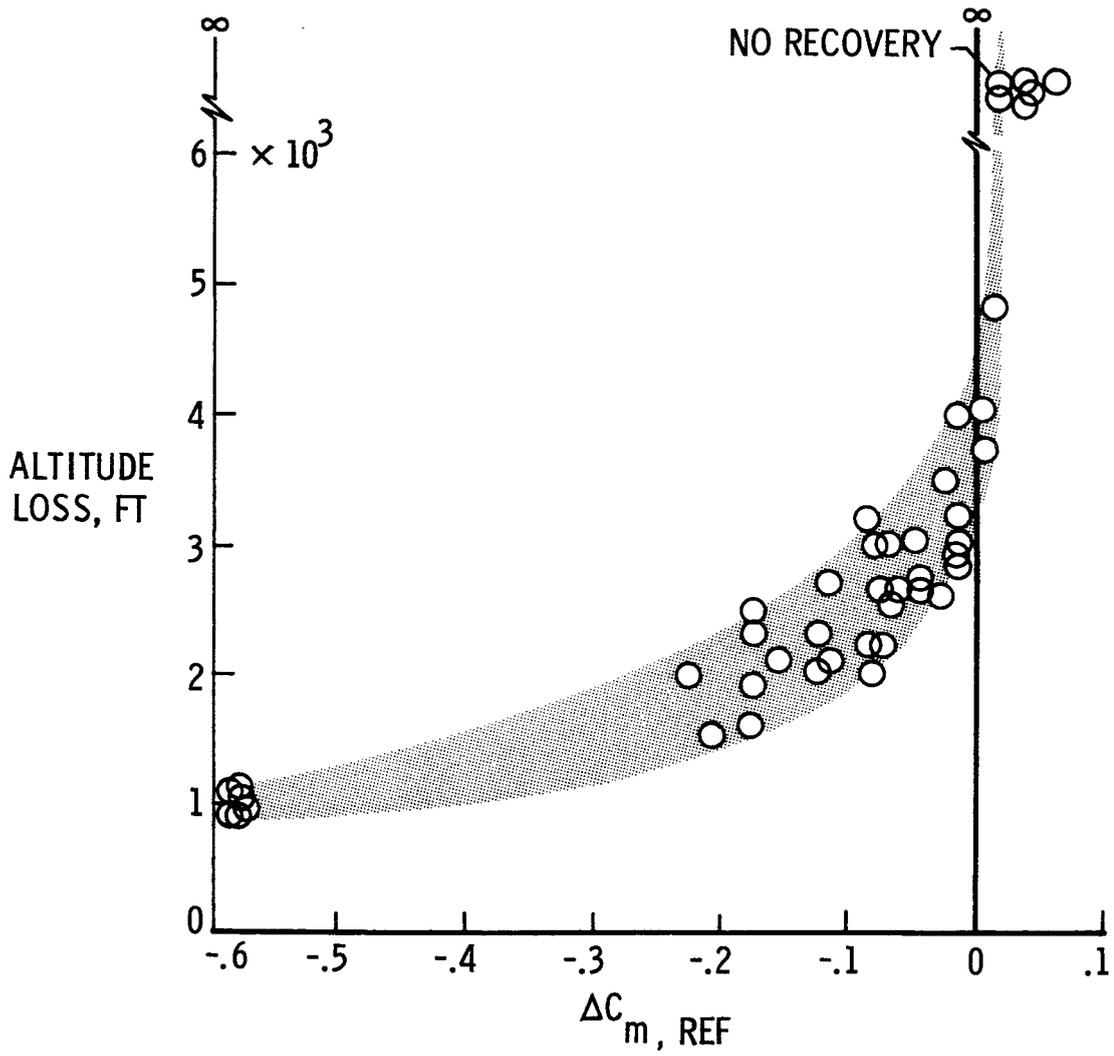


Figure 7.- Stall recovery - constant damping.

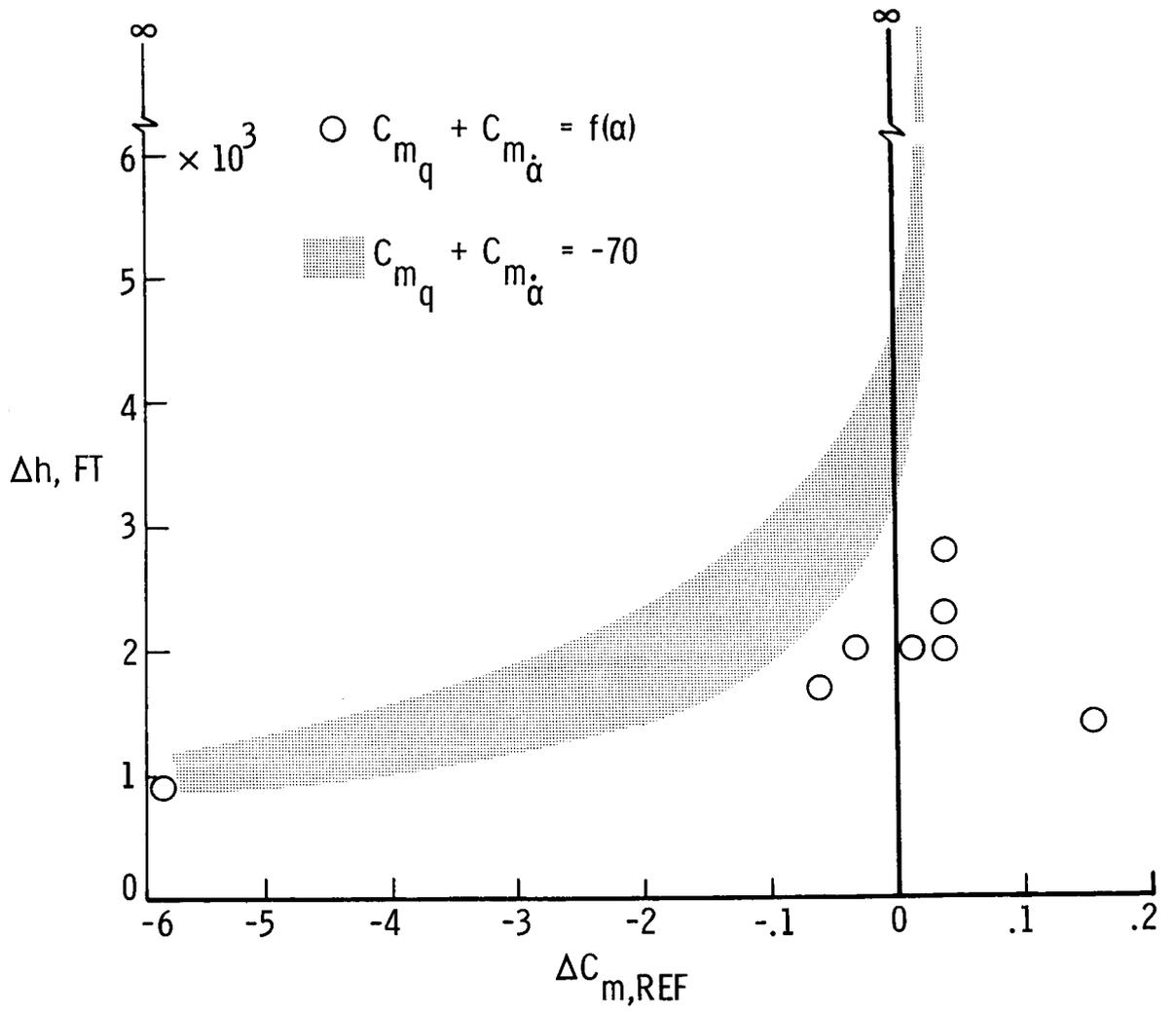


Figure 8.- Stall recovery with damping function.